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ENVIRONMENTAL EFFECTS ON ATTACK HELICOPTER CREW TASK PERFORMANCE IN THE NATO THEATER

by

Ad Hoc United States Army
Aviation Center Team Study Group

Edited and Compiled by
LTC Stanley C. Knapp, M.D.

May 1971

U. S. ARMY AEROMEDICAL RESEARCH LABORATORY

Fort Rucker, Alabama

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13. ABSTRACT

This report addresses the unique tasks, requirements and demands upon attack helicopter crews and the effects of the environment upon the performance of these tasks. Night operations under low ceilings, reduced visability, high or low speeds, nap-of-the-earth flight profiles and a threat of sophisticated antiaircraft weaponry is defined as the "worst-credible-environment" for the NATO theater. In this environment, the attack helicopter and its crew will be expected to fly a large percentage of its missions and deliver its ordnance with a high degree of accuracy.

Task performance is outlined in a detailed matrix. Collective tasks are grouped into functional task clusters. The effects of climatic conditions, the hostile threat, social and civil factors upon performance of these task clusters are discussed. The effects of the machine/mission created environment are presented and include hypoxia, toxic products, temperature extremes, visual and optical problems, acoustics, vibration, and human factors. Aircraft safety and reliability are directly affected by all of these factors.

Simple and practical solutions for nearly all factors presented are available with current technology. Application and implementation of these solutions, with explicit consideration given to environmental factors and human capability, will insure maximum performance from both men and machines.

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Flight Crews						
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Hypoxia						
Vision						
Acoustics						
Acceleration						
Perception						
Weapons Toxicology						
Safety						
Crash Worthiness						
Disorientation						

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Simple and practical solutions for nearly all factors presented are available with current technology. Application and implementation of these solutions, with explicit consideration given to environmental factors and human capability, will insure maximum performance from both men and machines.

Robert W. Bailey

ROBERT W. BAILEY
COL, MS
Commanding

FOREWORD

The Army Aviation Center Team Ad Hoc Study Group, chaired by LTC Knapp and composed of some of the best qualified and most knowledgeable experts in the aviation community, has addressed a subject of extreme importance. They have researched, reviewed, and analyzed hundreds of manuals, research papers and studies to assemble a complete and concise report on the environmental effects upon attack helicopter crew performance. The resulting document fills a void in the literature which should be labeled "required reading" for all those, especially at the command level, who are engaged in flying or who will employ aviation assets in support of their primary mission. This study is applicable to all phases of Army Aviation. Although it deals primarily with attack helicopters and their crews, the environmental factors presented affect all aviators and aviation equipment.

We of the Aviation Center Team feel this report will be of significant value to the decision makers within NATO and the US Army.

Allen M. Burdett, Jr.

ALLEN M. BURDETT, JR.
Major General, U. S. Army

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INTRODUCTION

This report addresses itself to the unique tasks of attack helicopter crews and the effects of environment upon the performance of these tasks.

No specific military role has evolved as rapidly, with so few precedents for direction and traditional solution, as that of the attack helicopter. Tactics, strategy or mission have essentially no heritage through other aircraft. Ingenuity, trial and error, and the crisis and exigency of battle have been the motives of this invention and the tools of the men who fly it.

Because the helicopter shares so few performance, mechanical, aerodynamic, tactical or stategic roles with other aircraft, it is influenced by the external environment quite differently from other aircraft. It creates a physical, physiological and psychological environment unduplicated elsewhere. The attack helicopter or "gunship" shares all the environmental factors of other rotorcraft, and creates a few new ones. It produces what the authors choose to call the "worst-credible-environment" for helicopters.

Nude, unprotected or unassisted man, like the aircraft he flies, was designed to operate within a certain environmental envelope. When asked to operate outside the "safe limits", a price is extracted which is paid by: (1) providing protective equipment; (2) providing "assist or support" systems; (3) degraded performance by the man; or (4) death. In most cultures or societies, death is not demanded. The problem resolves itself to this: when man is required to perform outside his safe operating envelope, he is required to balance the adverse effects of degraded performance against the encumbrances and trade offs of protective/assist devices for optimal performance of the man-machine aggregate.

The NATO long-Term Scientific Study report on "Effects of Environmental Factors on Military Performance", March - April 1969, identifies a comprehensive list of environmental factors and how they can be expected to degrade human performance. Nearly every factor discussed affects the attack helicopter crew. It is not the purpose of this report to review or redefine these factors, human tolerance to them, or outline performance decrements except as they are unique to the attack

helicopter crew's special tasks. This report's entire discussion can be applied to all helicopter crews with the understanding that many stresses may be absent or insignificant in other rotorcraft.

The NATO theater of operation provides the geographical setting for this report. It has, for all practicality, every conceivable type of physical, climatic, topographical, social, strategic, and tactical environment. The machines and their missions create the rest.

THE METHOD

From within the US Army Aviation Center Team, scientists, doctrine experts, engineers, physiologists, physicians, psychologists, experienced attack helicopter pilots, and instructors were assembled into a working group to address the subject. Each man, a recognized specialist in his field, provided the detailed inputs that have been condensed in this report. All were chosen for their recognized insight and knowledge of all aspects of helicopter operations, not just attack helicopters.

The international literature and myriads of unpublished military reports, plans and manuals were reviewed. The group then drew upon its individual and collective experience and investigations, integrated it and came to agreement as to the tasks, problems, environmental factors, solutions and conclusions presented here.

Reference material is presented only as necessary. Many papers would be unavailable to the casual reader of this report. The NATO paper cited above discusses in detail individual factors and should be referenced.

THE MACHINE

Description: The attack helicopter is unique to aviation. It is designed specifically for engaging and destroying hostile targets or to supplement fires of ground based weapons. Their flight envelope enables performance and missions unacceptable or impossible for other aircraft, either rotary or fixed wing.

Three types of attack helicopters are operationally conceivable, and each type creates its own characteristic environmental problems. The light attack helicopter may be a "converted" utility or light observation helicopter. The medium

attack helicopter is a pure attack helicopter designed and equipped specifically for this role. The heavy attack helicopter would include compounds (flight characteristics and performance of both fixed and rotary wing aircraft) and rotorcraft with unusual armament or performance characteristics. Each type has a relatively defined role.

Performance Environments: The attack helicopter has a band of performance sufficient to implement its role and bridge the gap between ground fire and more conventional attack aircraft. Airspeed ranges from a hover to dash speeds of over 210 knots and sustained flight of 145-195 knots. Flight durations, at any or all of these speeds, range from one to three hours. Ferry flights, without air-to-air refueling, may extend up to five hours.

Maximum performance is a philosophy that pervades all attack helicopter roles. Trade offs are made constantly between available power, gross weight and performance. These affect flight duration and distance, ammunition loads, operable ceilings, maximum air speed, thermal and noise signatures, and maneuverability, to mention just a few. Attack helicopters can function from sea level to over 15,000 feet with proper trade offs and compromises in performance. To hover at 4,000 feet, out of ground effect, and on a hot day, (95°F), demands maximum performance. This performance requirement places aircraft aerodynamics and human capability on the extreme edge of their ability.

Helicopters are peculiar to their limited use of "sophisticated black boxes", automation, and complex control subsytems. Helicopters have no inherent aerodynamic stability and are free to move in several different directions almost simultaneously. The helicopter can move forward or backward and roll about its long axis. Vertically, it is free to ascend or descend and rotate (pitch up or down). Laterally, it is free to move to the right or left and rotate (yaw). These are sometimes called the six degrees of freedom. This freedom of motion makes control complex and automation difficult.

No discussion will be made of environmental effects on machine performance unless human performance is also altered in the process.

THE MISSION

The mission is to engage and destroy hostile targets and supplement fires of ground based weapons in all types of weather. A diagram of a sample mission is shown in Figure 1, page 8.

Unless an assigned mission can be accomplished by the attack helicopter and its crew at some predetermined level of success, the aircraft has no usefulness. This report concerns itself with satisfactory mission completion regardless of environmental factors. If a factor degrades performance unnecessary to the mission, it is of no mission consequence. Unlike other aircraft, whose mission profile may be arbitrary, the attack helicopter must be flexible and uniquely effective, and without unnecessarily rigid mission or operational constraints. This unquestionably places the crew's performance at higher risk to degradation by the environment.

Mission Environment: Any attempt to specify precisely what a NATO Theater conflict would be, environmentally, is at best a qualified - speculative judgment, but some things are certain.

The attack helicopter will face vast numbers of armored vehicles accompanied by both radar and non-radar controlled antiaircraft weapons. There is the threat of missiles, heat seeking weapons, and the air-to-air weaponry of enemy aircraft. It is assumed that sabotage, air strikes, jamming, and spoofing actions against friendly navigation and communication facilities would be continuous. Night operations under low ceilings, reduced visibility (rain, fog and light snow) and nap-of-the-earth flight profiles will be the rule. The necessary protection of low attitudes (0-260 feet), trees, buildings and high speeds against hostile fire will result in one sure thing - regardless of the crew's aeronuatical prowess - wire, vegetation, building or terrain strikes will become more likely. All of the above represent the worst - credible - environment but the one in which the attack helicopter is expected to perform.

The base of operations (home fields) will be constantly moving. Improved airfields with optimum maintenance and support facilities will be the exception. Ammunition and fuel

will come from highly mobile supply sources. Rearming and refueling is conceived as being done while the engine is running, the rotor turning, and the crew is at its stations, ("hot" refueling). This may be in an open field, in rain, at zero degrees and/or while under fire. Previous experience with this concept has been restricted to hot or temperate conditions.

Personnel support will be little better, as presently conceived, from that provided the "soldier-in-the-field". The crew duty day can be expected to be long, demanding and fatiguing, with the rest obtained in a tent and often within range of enemy weapons. Weather, terrain or intensity of battle will not modify these factors except to worsen them. While these austere living and working conditions may be a tactical necessity, they will extract a high price in morale, performance and mission effectiveness.

THE MEN AND THEIR TASKS

Crew Complement: The primary crew consists of the pilot and copilot. They are present in every type of attack helicopter. Either may be in primary control of the weapons or aircraft.

The secondary crew is comprised of the crew chief and/or door gunners (1 or 2) carried on some attack helicopters.

Direct support crews include armorers, refuelers and flight line mechanics upon whose human performance may rest the maximal machine or mission performance.

Crew Tasks - General: The attack helicopter crew must learn a reflexive response to all task functions. There are at least nine combat formations and nearly as many target attack patterns presently identifiable as appropriate to the mid-intensity tactical milieu. These formations allow a variety of lateral and longitudinal distances, altitudes, and positions in order to maximize cover and concealment, permit rapid maneuvering and distribution of fire, while simultaneously insuring tactical effectiveness and survivability.

The Functional Task Cluster: The task functions to which the attack helicopter crew react have been identified and designated as functional task clusters (Tables I, Ia, Ib, Ic, pp 9 - 12).

They are not considered all inclusive, since omniscient crews are not available either! The tasks do indicate in sufficient detail the activity required of crews of tandem and multi-seated attack helicopters. Each element is critical

to mission accomplishment. Any decrement in performance that alters that element is unacceptable. As a minimum, specific performance decrements create additional risks to safety or mission accomplishment.

The flight control task cluster puts the man and all his facilities into the machine/mission milieu. Before the aircraft can function to any degree, inputs must be perceived from natural and artificial stimuli, then collated and integrated, judged against experience and training, balanced by fear and risk, and then applied to the flight control function.

The crux of the crew's role is the process of reducing general tactical plans into specific plans and actions for maneuvers, flight control, and weapons firing that are then coordinated with the actions of ground fire power and maneuver elements. A comprehensive analysis of this process, which is best described as a comprehensive heirarchal feedback matrix approach, is beyond this paper's scope.

Influences on Task Functions: The crew's functional task clusters, and ultimately their individual and collective performance and survival, are affected by two major influencing factors.

1. Factors of METT (mission, enemy, terrain, and troops).

2. Generally accepted rules for attack helicopter employment.

   a. Know the ground tactical situation.

   b. Know the mission and plan of execution.

   c. Avoid the "dead man-zone" (dictated by zone of effective hostile fire).

   d. Avoid flight parallel to terrain features (yet may be best flight path tactically).

   e. Always assume the area is hostile.

   f. Avoid target overflight (tactical situation may dictate violation).

   g. Locate friendly troops.

h. Avoid firing over the heads of friendly troops (violation in high intensity conflicts is almost certain).

i. Conserve ammunition and fuel.

j. Take your time.

k. Make a high reconnaissance (antiaircraft fire may prevent).

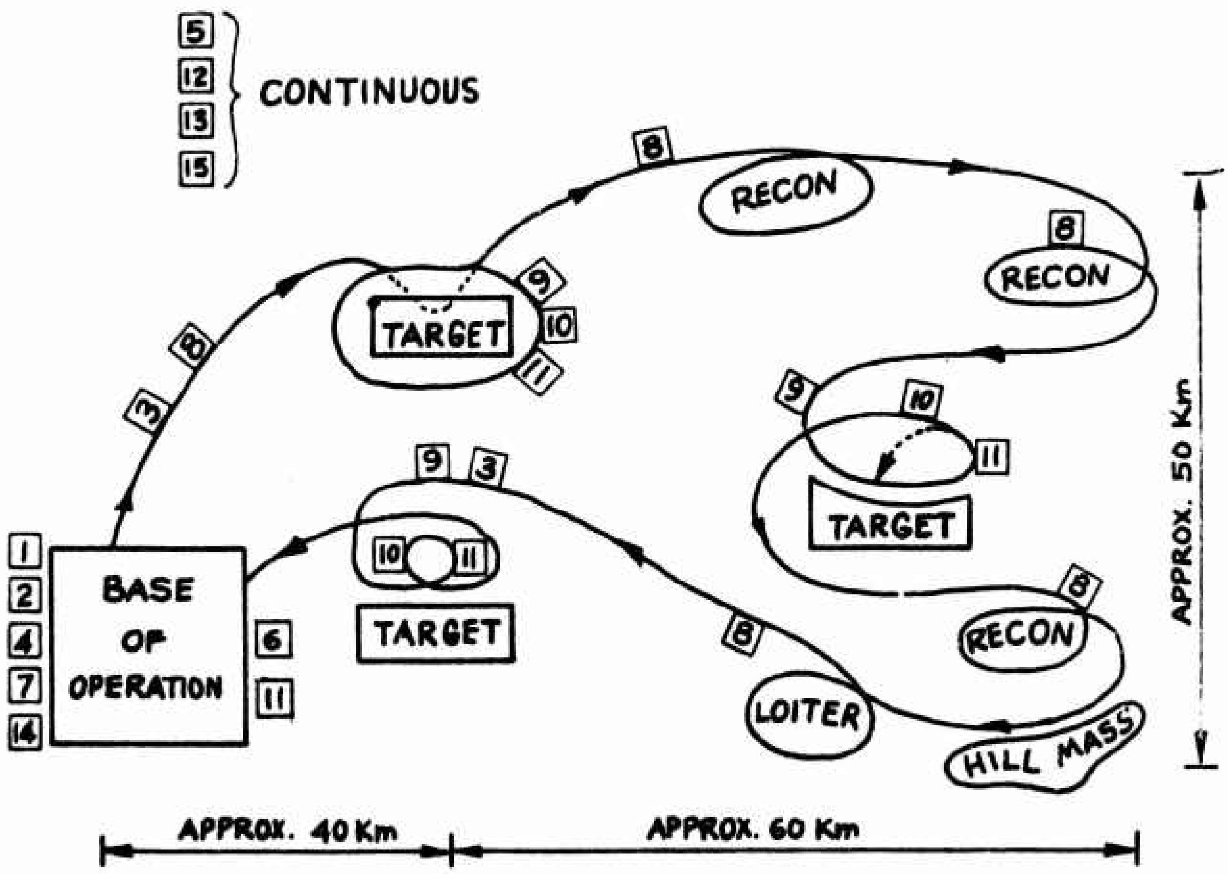
The Attack Mode Tasks: Four weapon firing modes are common to attack helicopters. Each is directly dependent upon armament configuration.

1. Area fire is intended as neutralizing in its effect. It is air-to-ground fire with rockets or automatic rapid fire weapons. Precision is not necessary but weapon control flexibility is important at distances up to 6,000 meters from the target.

2. Point fire is accurate and specifically designed to effect a "kill" with the first hit (launch). It is air-to-ground fire with missiles, rockets and automatic weapons. Integrated precision fire control systems with stabilized sights are necessary at the long ranges employed. "Stand off" engagement is possible with laser and infrared control systems. Present systems require target tracking for periods up to 25 seconds from a continuously vibrating and maneuvering platform.

3. Snap fire is the attack helicopter's "shooting from-the-hip". It is reflexive with any weapon system and defensive and neutralizing in nature. It requires maximum flexibility with great accuracy, and with minimal reaction time after perception and integration of the stimulus.

4. Air-to-air fire is conceivable with current machines in a mid or high intensity conflict. Any weapons system could be used in self-defense or in offense. The helicopter is often misconstrued as "free-game" to fixed wing aircraft. The attack helicopter has demonstrated that it is not necessarily so vulnerable.



Altitude:	Nap-of-the-earth to service ceiling.
Air Speed:	Hover to 140 knots ± 50.
Duration:	2.5 hours ± 0.5.
Weather:	Day, night, winter, summer, visual, instruments.
Fire:	Point, area, snap, air-to-air.

FIGURE 1. Typical mission profile for organic or general fire support. Numbers relate to task cluster [TABLE I] performed at selected periods.

		MULTI-SEAT AIRCRAFT				
		TANDEM-SEAT AIRCRAFT				
TASK CLUSTER	ACTION	ANALYZE	CONTROL	PLAN	PERFORM	ENLISTED CREWMEMBERS
1. PREFLIGHT INSPECTION	AIRCRAFT	X	X	X	X	X
	ARMAMENT(S)	X	X	X	X	X
	MUNITIONS, FUEL	X	X	X	X	X
2. REACTION TIMES	2 MINUTE (IN AIRCRAFT)				X	
	3 MINUTE				X	
	5 MINUTE				X	
	STAND-BY				X	
3. FLIGHT BRIEFING (may be given enroute)	COMMUNICATION	X				
	HAZARDS	X				
	TARGET DATA	X				
4. PRE-LAUNCH	PROTECTIVE DEVICES				X	X
	AIRCRAFT ENTRY	X		X	X	X
	START ALL SYSTEMS	X	X	X	X	X
	SYSTEM(S) CHECK	X	X	X	X	X
5. EMERGENCY	GROUND (STATIC)	X			X	X
	INFLIGHT	X			X	X
	HOVER	X			X	X

TABLE I

Essential crew task clusters that are largely base and flight line oriented.

		MULTI-SEAT AIRCRAFT				
		TANDEM-SEAT AIRCRAFT				
TASK CLUSTER	ACTION	ANALYZE	CONTROL	PLAN	PERFORM	ENLISTED CREWMEMBERS
6. POST MISSION	INSPECTION	X	X	X	X	X
	TACTICAL					
	RE-ARM	X	X	X	X	X
	RE-FUEL	X	X	X	X	X
7. FLIGHT BRIEFING	MISSION (TACTICAL)	X		X	X	X
	INTELLIGENCE					X
	EFFECT(S)					X
	MISSION (NON-TACTICAL)					X
8. FLIGHT NAVIGA-TION	MECHANICAL AIDS		X		X	
	TOPOGRAPHICAL AIDS	X			X	X
	CHARTS/MAPS	X			X	
9. GENERAL ATTACK HELICOPTERS	12 CARDINAL RULES	X	X	X	X	
	COMMUNICATION(S)	X	X		X	
	TARGET CATEGORY	X				
	ATTACK PATTERN	X	X	X	X	
	MUNITIONS	X	X	X	X	X
	RECONNAISSANCE	X	X	X	X	X
	DAMAGE ASSESSMENT	X	X	X	X	X
	SURVEILLANCE				X	X
	EVASIVE MANUVERS	X	X	X	X	
	FORMATION	X	X	X	X	
	LOITER	X			X	

TABLE Ia

Essential crew tasks that are oriented to the mission. The tasks appear to be brief but in reality are complex and more detailed than space will allow for presentation.

TASK CLUSTERS	ACTION	MULTI-SEAT AIRCRAFT				
		TANDEM-SEAT AIRCRAFT				
		ANALYZE	CONTROL	PLAN	PERFORM	ENLISTED CREWMEMBERS
10. SPECIAL	COMMUNICATION(S)	X	X		X	
	TARGET ATTACK	X	X	X	X	X
	MUNITIONS/WEAPONS	X	X	X	X	X
	EMPLOYMENT	X			X	X
	RENDEZVOUS	X	X	X	X	
	FORMATION	X	X	X	X	
	RECONNAISSANCE AND SECURITY					
	1. ACTIVE	X	X	X	X	X
	2. PASSIVE				X	X
11. WEAPON(S)	SAFEGUARD	X	X	X	X	X
	SELECT		X	X	X	
	OPERATE	X	X	X	X	X
	CALIBRATE				X	X
	RELOAD	X	X	X	X	X
	MAINTAIN	X	X	X	X	X
12. WEATHER FACTORS	VFR-DAY/NIGHT	X		X		
	IFR-DAY/NIGHT	X		X		
AVONICS	INTERNAL		X	X	X	X
	EXTERNAL					
	SINGLE CHANNEL		X	X	X	

TABLE Ib

Essential crew tasks that are oriented to the mission.

		MULTI-SEATED AIRCRAFT				
		TANDEM-SEAT AIRCRAFT				
TASK CLUSTER	ACTION	ANALYZE	CONTROL	PLAN	PERFORM	ENLISTED CREWMEMBERS
13. AVONICS (CONT'D)	MULTI-CHANNEL	X	X	X	X	
	EMERGENCY				X	X
	NAVIGATIONAL	X	X	X	X	
	SECURITY		X	X	X	X
14. DEPARTURE	IMPROVED FIELD	X		X	X	
	UNIMPROVED FIELD	X		X	X	X
	VISUAL DAY/NIGHT	X			X	
	INSTRUMENT DAY/NIGHT	X			X	
15. FLIGHT CONTROL	HOVER		X	X	X	
	CLIMB(S)		X	X	X	
	DIVE(S)		X	X	X	
	LEVEL		X	X	X	
	TURN(S)		X	X	X	

TABLE Ic

Essential crew tasks that are oriented to the mission.

THE EXTERNAL ENVIRONMENT

General: The mission and operational environments have been discussed as generalities. A few isolated elements have been identified. This section will further delineate environmental factors that are climatic, social and civic, hostile and mission/machine created. The reader must be aware that the definitive cause or even effect of each factor cannot be developed in this paper. Each factor presented has been clearly identified through operational experience or investigatory techniques.

Individual environmental factors never have their effect as isolated stresses. Synergistic, additive, antagonistic and even paradoxical relationships result in the REAL LIFE EFFECTS on performance. These relationships and interactions are not well defined. For this paper it can be assumed that any factor presented will have a synergistic or additive effect.

Man does not adapt or acclimatize well to a dynamic environment. It may be dynamic because the man is in-and-out of the environment or through continual environmental change.

Climatic: The NATO theater has a nearly infinite range of climatic conditions. Mean values for days of fog, days of rain, temperature, inches of snow and relative humidity vary so widely between geographic areas that from experience, a basic assumption is made:

> An attack helicopter anywhere in the NATO theater will be required to perform a significant number of its missions in the worst-credible-environment.

Terrain elevation extremes, from sea level to mountainous, only compound flight and physiologic performance degradations. Wet-humid to dry-arid conditions are present, as well as sub-zero-icing with snow. Severe local weather conditions (thunderstorms) have a profound psychological effect on the crews and an adverse aerodynamic effect on the machines.

Social and Civil: This area is complex. Adaptability, feedback mechanisms, social mobility, crowding, role conflict, organization structure and political stress affect performance.

Conflicts between shared or alien value systems affect individual and group empathy and image of worth. Language barriers affect air-to-air and air-to-ground-to-air communications. Nonpotable local water and food sources have their effect physiologically. Civic customs and traditions, and more importantly, the inherited methods of logic and reason, affect the proper perception of one's environmental milieu.

Hostile: Anything that poses a threat could be called hostile, especially if it cannot be foreseen or predicted. Understanding enemy capability and tactics, and then thinking like the enemy, will be paramount to mission success and survival. The threat of unseen or unheard enemy air or ground weapons, tracked by sophisticated systems, have an immediate and long term effect on motivational versus risk criteria. This in turn modifies, usually unconsciously, a crew's willingness and/or ability to fly difficult missions. Dynamic climatic conditions have the same effect.

THE MISSION/MACHINE INDUCED ENVIRONMENT

Lack of Oxygen: A serious primary physiologic risk to the high performance attack helicopter crew is hypoxia (lack of oxygen) with increasing altitude. Hypoxia is extremely important in NATO theater operations of attack helicopters for many reasons:

1. Increased altitude capabilities of aircraft.

2. Increased terrain altitudes.

3. The pilot provides system stability to the helicopter. Constant vigilance is required with precise stimulus perception and physical reaction taking place in the shortest possible time frame.

4. Current attack helicopters have no oxygen systems.

5. Additive or synergistic effects of:

   a. Smoking.

   b. Night operations.

   c. Alcohol intake and hangover.

   d. Carbon monoxide.

   e. Fatigue.

f. Certain medications.

g. Closed cockpits with poor ventilation.

Hypoxia is simply decreased oxygen levels available in the blood for metabolism and thinking. It is a time and altitude dependent phenomenon. The effects of hypoxia begin with loss of night vision capabilities at 5,000 or 6,000 feet above sea level (MSL) and progress to total incapacitation at 15,000 - 18,000 feet MSL.

Following loss of night vision capability there is a rapid loss of integrated thought processes. Memory ability decreases. Judicial ability diminishes especially concerning time - space relationships. Instrument scan times increase and perceptive capabilities decrease. Sensory stimulus thresholds increase. Communication deteriorates with failure of intuition, memory and speech pattern recognition.

Unconsciousness occurs at 20,000 to 22,000 feet MSL if supplemental oxygen is not available.

Above 10,000 feet MSL, the duration of good physiologic or psychologic performance diminishes rapidly with each additional 1,000 feet. In general, a person acclimated to sea level can perform sedentary work at 10,000 feet for several hours without symptons. Night vision, however, will be markedly reduced and headache and fatigue can be expected on acute exposure. Rapid heart rate, breathlessness, headache, loss of appetite, insomnia and extreme irritability will definitely occur after a 4 - 6 hours exposure to this altitude.

Toxic/Noxious Gases: Respiratory toxicants are of great significance. Most are products of incomplete combustion either of engine fuels or armament propellants. Carbon monoxide (CO) is the most common, insidious and lethal. CO is the primary respiratory toxicant of smoking. CO competes with oxygen causing a type of hypoxia. A level of .01 per cent (100 parts/million) CO is the accepted industrial threshold for an eight hour day.

Turbine powered helicopters, moving during weapons firing and with good cockpit ventilation, have not shown significant CO accumulation. Faulty seals on the weapon systems, or inadequate ventilation may create an immediate but undetected performance degrading environment due to CO contamination. CO and increasing altitude work synergistically and additively. Smoking effectively reduces tolerance to altitude by several thousand feet. Thus, a heavy smoker flying nap-of-the-earth, at night, at a terrain elevation of 3,000 feet MSL, is in serious trouble but does not know it (Figure 2).

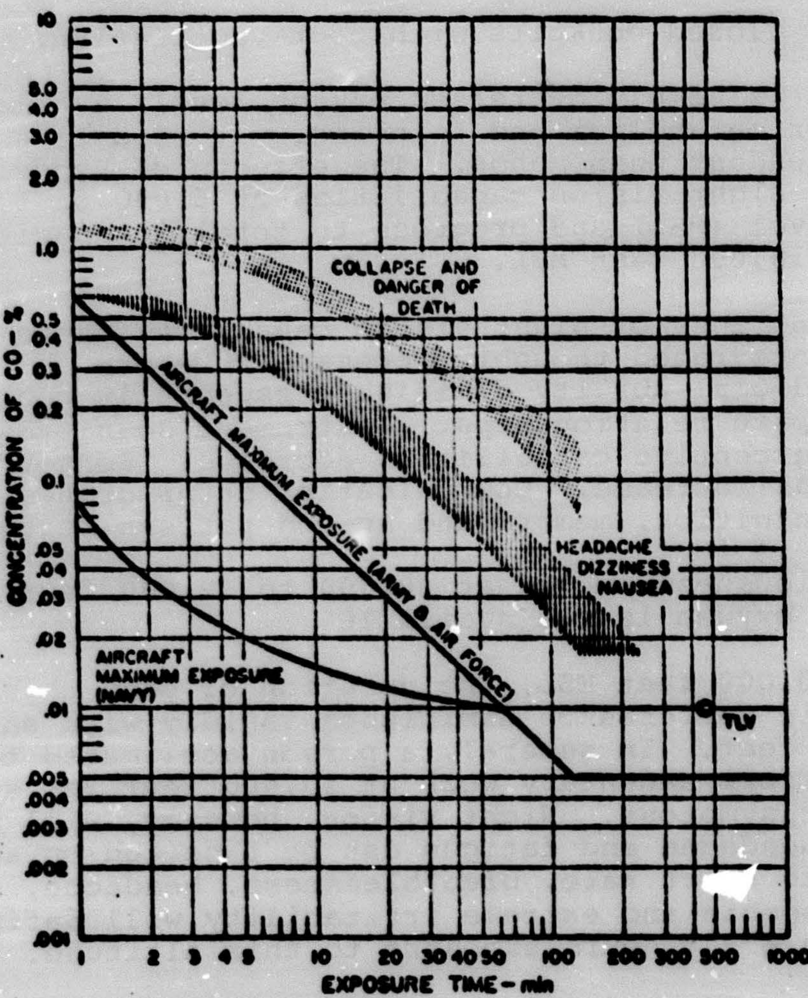


FIGURE 2. The graph shows the effects of carbon monoxide on man as fuctions of concentration and exposure time. Milder effects are shown as a lightly shaded band of exposure times and concentrations, while dangerous or lethal times and concentrations are grouped in the heavily shaded band. The solid lines are the exposure limits set by the military services for aircraft.

(BACK, THOMAS, & PINKERTON, 1964; SOURCES: DEPARTMENT OF DEFENSE; HALDANE; HENDERSON & HAGGARD; & SAYERS ET AL.)

Other toxicants occur simultaneously with CO especially from propellants. The effects of many are unknown but experience indicates they are not a primary mission or performance hazard. They can, however, result in long term physiologic damage. These agents include various organic acid gases, hydrocarbons, heavy metals, ammonia, volatile alkaloids and solid particulates. Nicotine has a neurotoxic and enzyme toxic effect. While not of known significance in aviators, tetrahydrocannabinol (marijuana) is of importance in oxygen metabolism and has dangerous neural effects.

Temperature Extremes: The single greatest threat to the attack helicopter crew by lowered temperature is the loss of critical dexterity of any extremity. Physiologic aberrations (reduction in core temperature) are as serious but not as immediate in their effect. The helicopter crew is vulnerable to exposure to temperature extremes by virtue of the following listed items. They are not necessarily complete. Wet Bulb Temperatures are represented by WBGT. The WBGT is a comfort index derived from various temperature and relative humidity measurements.

1. Wide range in ambient climatic temperature (subzero - 100°F).

2. Narrow range of unprotected thermal comfort (WBGT 75°F - 85°F).

3. Synergistic effect of cold by ambient wind, rotor wash or a doors open configuration.

4. Synergistic effects of heat created by the greenhouse phenomenon (ambient WBGT + 20°- 30°F).

5. Encumbrance, lack of ventilation and heat load imposed by mandatory protective clothing, personal armor, etc. (+5°F skin WBGT over ambient).

6. Incompatability of protective gloves and boots with controls.

7. Incompatability of winter clothing bulk with protective armor, survival vests, restraint harness and seat anthropometrics.

8. Total lack of, or lack of effectiveness of existing environmental control systems at extremes of temperature range.

9. Slow acclimatization to heat (1 - 2 weeks).

10. Rare acclimatization to cold.

11. Conductive heat sink of frequent contact with metallic objects in cold weather (Rearming weapons).

12. Evaporative cooling of frequent contact with fuels.

13. Incompatability of heavy gloves with required dexterity to service aircraft and its subsystems.

14. Field living conditions during rest periods.

At ambient temperatures of 85°F and above, radiative, conductive and convective cooling are insufficient to achieve thermal equilibrium; consequently, perspiring occurs which permits evaporative cooling to be added to the other three physiological cooling processes. During muscular exertion in a hot environment, perspiratory secretion may reach values as high as 1,600 milliliters per hour, and in a dry atmosphere most of this perspiration is evaporated. Heat loss by vaporization of water from the skin may vary from 30 to over 900 kilocalories per hour depending upon the relative humidity. If the summation of heat loss by convection, conduction, radiation and evaporation is less than metabolic heat production, total body temperature begins to rise. Eventually, the heat regulatory mechanisms are overwhelmed, and serious disease can occur. In general, 60-80 kcal/hr is as much heat exchange as man can tolerate for sustained periods. Adequate fluid replacement is difficult, if not impossible, during flight.

It has been shown that attack helicopter crews can perform moderately well in a hot, humid environment with proper acclimatization. Experience has also shown that closing the cockpit, as in medium or heavy attack helicopters, thermal loading is severe and air conditioning is required. The thermal threat is greatest during ground or hover operations. If air flow exceeds the 300-800 feet/minute velocity recommended for convective and evaporative cooling, there is sufficient cooling to permit long-term safe operations.

A 1966 conference of environmental specialists on the heat threat to helicopter crews recommended:

1. A cockpit WBGT index of not greater than 88°F while aircraft are on the ground or at hover.

2. A WBGT not greater than 85° in flight and not greater than 80°F when wearing protective armor, et cetera.

At ambient temperatures of 75°F and lower, one is subjectively cold because stored heat is lost. As skin and then later as core temperature begins to fall, shivering may occur which greatly increases metabolic heat production and oxygen demand (additive to hypoxia). Cutaneous vasoconstriction becomes maximal and "goose-flesh" develops, which is man's meager efforts at piloerection. Final breakdown of thermal control depends upon the degree of physical activity, the amount of clothing protection, and the duration of exposure; however, when core temperature reaches 86°F, (normal 98.6°F) death will occur, except under stringently controlled conditions. If activity is restricted, the extremities, and in particular the fingers, toes, nose and ears, approach freezing temperatures. Unless corrective actions are promptly taken, tissue damage will occur. If the individual is physically active, cooling occurs more slowly. Fatigue, however, develops rapidly and as exhaustion approaches, the vasoconstrictor mechanism degrades and massive vasodilatation occurs, causing rapid heat loss and critical cooling.

Protective clothing has an insulative function against cold. The unit of insulation is a "clo". A clo is defined as the amount of insulation which will maintain normal skin temperatures when heat production is 50 kilocalories/meter2/hour, air temperature is 70°F and air movement is 20 feet/minute. One clo corresponds to clothing worn by a man in a temperate zone during the summer. A standard helicopter crewman's winter uniform of cotton long underwear, thermal long underwear, winter flight suit and winter flight jacket constitutes 2.5 clo. This will protect a man in 35° - 45°F temperatures indefinitely.

The limit of insulation with clothing is 4 clo, because such clothing is about one inch thick and represents the practical limit of permissive bulk and weight. In helicopters, 2.5 clo is as much as man can tolerate and still perform his tasks.

It is unfortunate that the two areas of greatest thermal risk - the feet and hands - cannot be protected with ease. Protective thermal boots seldom exceed 2 clo because of physical limitation imposed on the wearer. Only a fraction of a clo can be applied to the hands and maintain good control (cyclic stick) sensitivity. Electrically heated socks and

gloves may be necessary.

Wind chill is the skin temperature lowering phenomenon of wind in any environment, but it is worse in cold. In the environment around helicopters, wind chill is particularly important since ground crews are commonly exposed to downwash during work periods on aircraft ramps, and open doors also expose the crew during flight. Times of potential severe exposure include hot refueling, rearming operations and door gun operations. Wind tunnel studies indicate that mean skin temperature can fall as much as 39°F in 20 minutes with an ambient condition of 50°F, 50 miles per hour winds, and the human subject wearing standard winter flight attire providing an equivalent of 2.5 clo. This environment could easily be achieved in the downwash of any attack helicopter. If wind penetrates the surface of clothing or enters openings at the neck, waist, sleeve or trouser cuff, as much as 30 per cent of the insulation intrinsic in the garment may be lost through forced convection of the entrapped air.

Visual and Optical: Visual acuity, orientation and the ability to adapt to low light levels are the most critical visual factors affected by the environment of attack helicopter flying.

Mid-air collisions are a definite problem in formation flying or high aircraft density operations. The pilot must see and avoid other aircraft. Aircraft conspicuity can be enhanced by high intensity lighting systems. Currently under development are systems employing a controlled beam of light and these appear to be tactically acceptable. Proximity warning devices are needed for the low visibility/high closure velocity environment of these aircraft.

The crew must be protected from potential nuclear weapons flash, against high brightness light levels outside the cockpit (sun, snow, glare) and yet be able to see and read their instruments. Helmet visors must protect against bright light, weapon debris, obstacles in a crash, injury from fire and be compatible with corrective spectacles. All of these items are usually incompatible with optical perfection (chromatic and spherical) and weapon sighting. The presence of rain, bugs, scratches or imperfections on the aircraft windscreen or helmet visor seriously reduce the ability to make critical visual discernments.

Exotic aircraft-mounted equipment presents problems such

as need for laser beam protection, flicker vertigo (flashing lights or flicker at frequencies sufficient to cause a change in a person's state-of-awareness or perception), contrast differentiation and physical eye safety. IFR (instrument flight rules) and reduced visibility flying under stable or maneuvering high G conditions are almost sure to produce sensory and visual illusions. These result from a sensory incongruity of visual, somatic, vestibular (inner ear) and auditory inputs. They are usually fatal in the low and fast flying environment.

At night, virtually all of the above problems exist with some additional ones. Readability of instruments and uniform instrument lighting at levels that do not affect dark adaptation is mandatory. The lighting must not increase the visual signature (target) of the aircraft. Protection against windshield glare (internal or external) and high battlefield illumination (flash and flares) pose difficult problems. External lighting for conspicuity, formation flying and target location create unacceptable but necessary environments. Weapons flash is a distinct threat to dark adaptation. Night induced visual illusions can be extremely dangerous, especially when "low and fast." Autokinesis (apparent movement of a point source of light when in fact there is no movement) and ground light/star confusion are precipitated only at night.

Physiologically, the entire visual environment is worsened by hypoxia and vibration (discussed later). Hypoxia is a threat; vibration is a reality.

<u>Acceleration and Disorientation</u>: The attack helicopter provides an acceleration profile or lack of it which is unusually conducive to all forms of disorientation (pilot vertigo). Very slow velocity changes, either linear or radial, may have values below physiological perception. If the aircraft is free to move in any of its six degrees of motion freely and without crew awareness, the results can be catastrophic.

Medium and heavy attack helicopters are capable of pull-ups and turns that create up to three G's of acceleration. Couple this with the simultaneous ease of motion in a different direction and often the result is the so-called vestibular coriolis phenomenon. Low and fast flying is in no way compatible with these illusions. Instrument systems that do not relay clear, concise position information on a single glance only compound these hazards. In fact, disorientation is the inability to perceive correctly what is happening or has

happened to the aircraft in space.

Sophisticated weapon control systems utilizing optical subsystems that swivel/rotate, constrict peripheral vision, necessitate target fixation or rely on rotating gunners seats, jeapordize the ability to track the weapons. They also cause disorientation. A non-violatable rule in high G maneuvers is to "lock one's head and body to the aircraft" and never move one's sensory organs out of the primary path of aircraft movement.

The accelerations of attack helicopters are not generally severe enough or prolonged enough to cause hemodynamic physiological problems such as blackout.

Impact accelerations are largely vertical in orientation and result in significant back injuries. An autorotating or free falling attack helicopter, with rotor turning and altitude stabilized, has a descent velocity up to and over 3,000 feet/minute. The margins for proper execution of the recovery phase and soft landing of an autorotative procedure are distressingly precise. Performance decrements acceptable anywhere else in the mission profile may, on the basis of experience and investigations, result in an autorotative crash landing. Even so, the tremendous impact forces can be attenuated or absorbed through crashworthy design described later.

Vibration: Attack helicopters have a significant vibration profile. Most of this profile is generated by the rotor system. The turbine engine and associated transmission have a lesser effect than in other aircraft. Of concern, is the effect of vibration displacement and maximum acceleration in G's on the mechanical and visual aspects of performance. There are, of course, others.

The vibration spectrum of attack helicopters is not well known. It varies greatly with rotor disc loading, blade tracking and effectiveness of isolation and damping devices. From extensive vibration research in other vehicles and what is known about the attack helicopter, the vibration spectrum is probably sufficient to cause chronic changes to the skeletal system of the body and produce pain. While of no immediate effect, constant backache is fatiguing and distracting. There is suspected synergism between chronic vibration and seats that are anthropometrically poor.

Constant vibration of poorly damped instruments create

serious perceptual errors. Efficiency of visual tracking is also impaired by vibration. To it add loss of manual dexterity and finite touch, and the pilot finds that fine control movements are impossible. Manual/optical tracking of weapons becomes less than accurate. Helmet mounted sights tested to date have been found to be relatively inaccurate at extreme ranges for point fire and are likewise affected by vibration. It is nearly impossible to sight through a shaking, bouncing optical reticule. The sight reticule must be stabilized.

Acoustic: Attack helicopters create tremendous amounts of noise which has a direct effect on crew performance. Rotor systems, engines, transmissions and air flow produce their share. Weapon systems generate high level impact (impulse) noise. The proximity of these weapons to the crew and lack of physical shielding contribute to the hazard. Lack of free field noise masking and inherent noise levels in the communication system provides for an additonal acoustic hazard.

The present accepted damage risk criterion for impulse (weapon firing) noise is 140 db (decibels) peak sound pressure level. For steady state noise, the accepted maximum levels without protection are 92 db in the octave band between 150-300 Hz (cycles per second) and 85 db for all octave bands between 300 and 10,000 Hz.

In general, the peak sound pressure levels of weapons on attack helicopters are well above the 140 db criterion (Figure 4). The range of peak levels may be 150 - 170 db. Steady-state cockpit nose, especially during maximum performance maneuvers, may be continuous 100 - 120 db (Figure 3). Current voice communication systems have steady noise levels of 85 - 115 db.

Therefore, there is no question that noise will extract its price in performance. Irreversible hearing loss will inevitably result, if the crewman is not afforded adequate protection. Acute effects include direct interference with perception of auditory inputs from the air or ground (enemy ground fire), and the crew's ability to communicate. Distortion of communication has its effects as does any suppression of auditory warning safety devices (low RPM, etc). Not of less importance is the known effect of noise in creating fatigue.

Essential protection for the crew consists of adequate sound protective helmets, ear plugs and the necessity to design noise out of electronics and machinery.

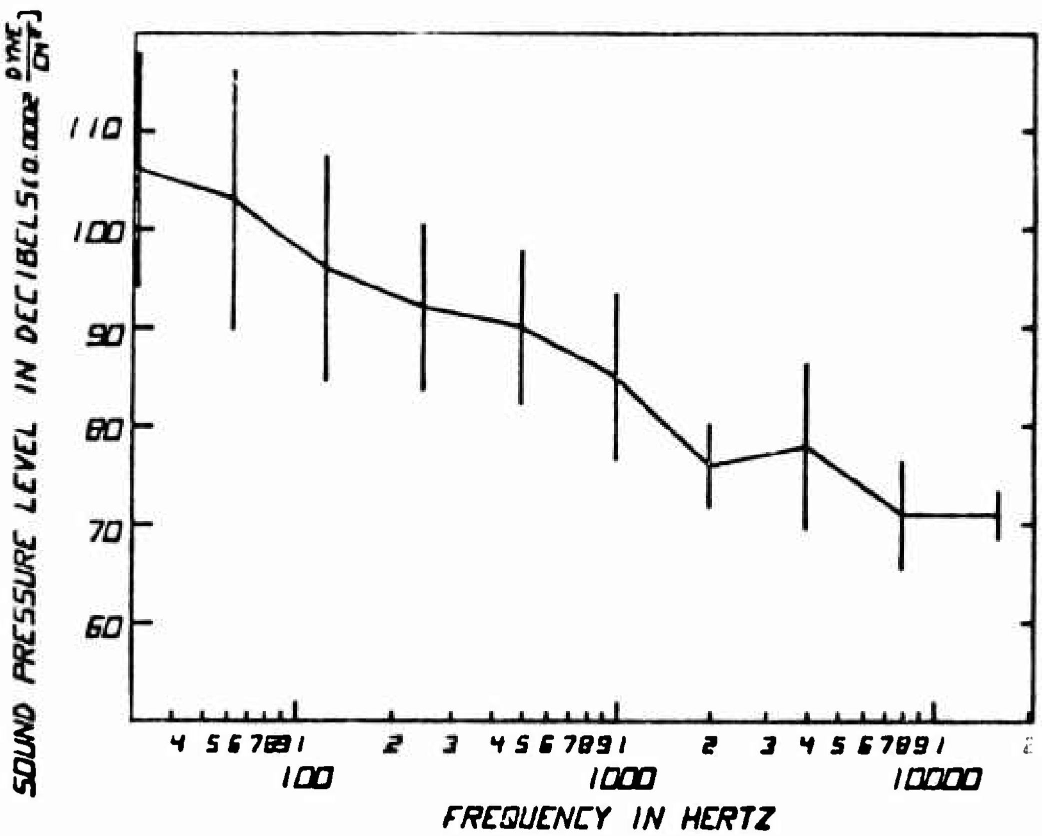


FIGURE 3. Crew compartment noise from a medium attack helicopter in flight. Communications noise and weapon noise is not represented. Damage risk criterion are exceeded.

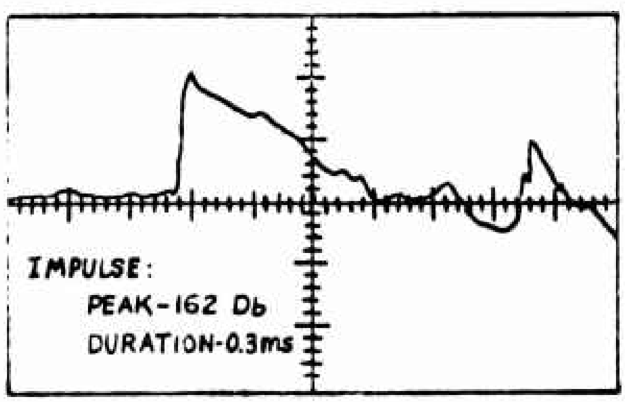


FIGURE 4. A representative graph of attack helicopter machine gun impact noise at the muzzle. Distance and a closed canopy attenuated the 162db peak to 132db at the proximity of the copilots ear.

Safety, Reliability, Survivability: Weight-power trade offs affect the availability of safety equipment and crash/ballistic worthiness of helicopters in general. Maximum power settings result in shorter times between failures of all drive train components. Inspection and maintenance tasks will need to be performed more frequently and intensively in the field. Use of dye penetrants and magnification lenses may be necessary. The general environment, however, may not be compatible with this necessity.

Protection against crash forces is directly related to the mission if we wish to insure return of the crew to fly again. As was developed in the section on mission environment, accidents will occur - many needlessly. Prevention/protection against crash injury is a matter of design. Energy attenuating seats and fuselage structures, better restraint systems, de-lethalizing cockpits of sharp objects and debris will diminish the hazard.

Crews have no means of aircraft escape while airborne. Cockpits are too confined and routes of escape too complicated with obstructions. Low level flight does not allow sufficient distance for parachute deployment even if the main and tail rotor posed no threat to entanglement. Ejection or extraction systems have been developed for helicopters. A recent study revealed that 40-50 percent of attack helicopter fatalities resulting from in-flight emergencies might have been prevented by such systems.

Fire has always been a distinct hazard to helicopters. Positioning of the tanks under the crew compartment or in bulk heads that will be ruptured on ground impact are sometimes unavoidable compromises of design. Design for crash worthiness (rupture resistant tanks, breakaway non-leak fittings, etc.) is now state-of-the-art. Without these systems, even a minor fire becomes catastrophic. Thermal protective clothing for the crew provides a short duration micro-environment of protection. Until aircraft fires can be eliminated or prevented entirely, this clothing is necessary.

Ground-to-air or air-to-air weaponry creates an inhospitable ballistic environment both to vital aircraft components and crew. It is clearly established that man's aerial performance is reduced if not destroyed by even minor wounds, and the mission is severely compromised.

Human Factors: In daylight, a pilot can fly a helicopter at low levels and fire weapons at planned targets without

significant difficulty. Daytime low level flight while (1) navigating, (2) detecting the enemy, (3) maintaining orientation in the local engagement area with regard to terrain features and enemy and friendly forces, (4) coordinating actions, and (5) effectively returning reflexive "snap" fires against non-suspect sources of fire, are crew tasks accomplished with standards of performance sustantially below that which are desired.

At night or in limited visibility at low level, the difficulties in performing the five tasks itemized above are accentuated. The tasks of flying the aircraft, and avoiding terrain obstacles and other aircraft ascend to a role of primary importance and considerable difficulty. In addition, the process of information acquistion, integration and interpretation becomes an extremely demanding task in any available or projected attack helicopter as they are currently equipped.

Human factors considerations indicate that the information requirements of the attack helicopter for night or all weather low level missions are beyond the capacity of fixed-wing instrumentation concepts found in most current helicopters. The propensity for error and leisurely response time that characterize fixed wing instruments simply are not acceptable for this demanding helicopter mission. Helicopter instrumentation capable of accommodating all mission information requirements with rapid error-free reactions appear to be essential.

For the crew in the night or all weather low level situation, the informational environment in the cockpit dominates all others in determining the effectiveness and safety with which they can perform their mission tasks. Accurate and timely information increases the crew's resistance to stresses of other adverse environments. Therefore, the primary environmental problem from the human factors standpoint is the cockpit itself, and in particular, the informational environment it provides.

For missions in the worst-credible-environment, crew confidence in their instrument systems will be dependent to a great degree upon the ability of these instruments to measure accurately and then display the information that is critical to the mission.

This crew confidence is closely related to the reliability with which critical information sources will operate (air speed, absolute altitude, attitude, warning systems). In addition, task complexity and the ultimate availability of these information sources on the battlefield exert influence on crew confidence. From the standpoint of mission survivability, the use of wide area radar emitters will become less and less advisable on future battlefields. Furthermore, external sources of navigation reference may prove to be unreliable. The crew cannot be trained or expected to have confidence in systems that are not certain to be available to them on the battlefield. They must consider them a bonus to be used if available, but must place their trust in other systems in which they are confident will be available.

Human factors problems are compounded by established autonomy in the individual instrument display philosophies. For the attack helicopter crew, all the information provided them must fit together well enough spacially and perceptually to permit appropriately timed decisions and responses to the mission tasks. Simply stated, instruments provide visual or auditory stimuli that require interpretation and response. How these stimuli are presented must be uniform, precise and simplistic. The logic or methods required for interpretation must be similar. Control movements should correpond to the required reaction, for example, push forto go. Control shapes and surfaces must <u>not</u> be uniform within any aircraft (but common to all) so that the stimulus of touch alone is sufficient to interpret the type of control and control position. Operation of controls must not task the manual or mental gymnastics of the crew. Instead, there is a profusion of specific instruments for specific information requirements, resulting in more than a dozen information frames of reference. The resulting mass of required transformations overwhelms the crew. Placing five round subsystem control knobs, each with multiple postions, on square junction boxes, attached to a major flight control, will inevitable result in inadvertent weapons firing when landing lights are wanted.

Universal off-the-shelf instrument packages or cockpits designed without appreciation for this special environment will simply not work - at least to provide maximal crew and machine performance. The potential contributions of the crew are often ruled out in design considerations forcing an unnecssarily complex automatic solution without manual override.

Complex avionics (radios and direction finding equipment), machinery, weapons and control systems cannot be serviced or maintained at the optimum level in the operational/ mission environment described. Closed circuit refueling systems, prepackaged ammunition, shelters that are portable and climate controlled, efficient de-icing equipment and modular system design can partially eliminate some environmental effects.

Application of anthropometry has its direct effect upon human factors. Control positions and seat adjustments must be compatible with the 5 - 95 percentile anthropometric aviators. Cockpits requiring the 10th percentile sitting height and 95th percentile arm and leg length may be the product of equipment designers who have no concept of human factors. These design errors clearly extract their toll in increased accidents for the crew members who do not conform to such unrealistic authropomorphic requirements.

SUMMARY AND CONCLUSIONS

The worst-credible-environment in the NATO theater for the attack helicopter would be at night, with conditions of low or zero visibilty, operating at extreme low level, high speeds, high G maneuvers, during winter, in and out of mountain valleys, 30-40 miles from its base of operations and against an armored enemy with accurate and sophisticated anti-aircraft weaponry. This performance environment is so alien as to preclude flying by nearly every type of aircraft. Yet, the attack helicopter crew is expected to deliver precise point fire and be flexible enough for accurate snap fire.

Within the milieu described, the crews of attack helicopters will be expected to fly a significant number of their missions. It is these climatic conditions that provide the best tactical and concealment conditions, and afford the best opportunity for mission survival. It is the helicopter that is expected to function in this operational envelope.

Performance can be and is severely affected by environment conditions caused by the machine or the mission. If crews know from experience that nocturnal high G maneuvers at low level cause disorientation and crashes because of inadequate insturments and spacial attitude displays, then they simply will not fly that maneuver. The maneuver omitted may be critical to tactical effectiveness or survival. The aircraft is then not being utilized to its maximal potential.

Hypoxia will be a factor affecting every aspect of performance, especially vision in night operations above 6,000 feet MSL and day operations above 10,000 feed MSL unless supplemental oxygen is provided. Serious risk to man and machine is taken at any altitude above 12,000 feet MSL for any length of time without oxygen. Carbon monoxide and other toxicants will lower these ceiling altitudes significantly.

Extremes of temperature can be expected to seriously degrade crew performance. At WBGT indices of 80°F and above it will be uncomfortably hot, and fluid and electrolyte balance can be expected to be deranged. At 40°F or below, hands will be cold, and manual dexterity severly impaired. Heavy

insulative clothing cannot be worn because of bulk and anthropometric considerations. Cockpit environmental control and shelters will be necessary.

Critical visual performance is degraded by hypoxia, drugs, illusions, vibration and the optics of visors, sights and windscreens. Sensitive night vision is rapidly and seriously affected by glare, cockpit lighting, conspicuity lighting, weapons flash and others. Variation in instrument display philosophy tasks visual performance beyond what can be expected to be good.

Acoustic stress of high free field cockpit noise, distorted and high noise levels of communications systems and severe impact noise of weapon firing will cause permanent hearing loss and degrade perceptual tasks.

Sensory illusions and disorientation of flight are inevitable; but with training and provision of adequate instrument information systems, the hazardous results are preventable.

Vibration extracts a performance price in immediate degradation of dexterity, visual tracking, long term fatigue and suspected skeletal changes.

Fire, impact forces, less than adequate egress systems and non-crashworthiness compromise human survival of anything but minor accidents or inflight emergencies.

The aggregate of human factors and perception initiated actions are so vast as to be inseparable from machine design and human capability. Design must be simplistic, systems integrated and oriented to crew tasks and environmental constraints.

All environmental factors are additive or synergistic, having peripheral, as well as direct effects. Man is slow to adapt psychologically and phsiologically to static environment, but will, if given enough time. To the dynamic environment, however, he rarely adapts and consequently, must be supported.

Although the problems of the attack helicopter are unique, they are not unfamiliar or particulary new. This report has addressed those that are of the most pressing importance. Research programs to identify new problem areas are not a primary necessity. Satisfactory solutions exist for practically every problem this report has discussed. These solutions are available with current technology. What is needed are programs

to implement and apply the simplest and most practical solutions to these identified problems. Complex and sophisticated solutions are of doubtful value. Whatever the solution, it must not be ignored that man has his limitations as does his machine.

REFERENCES

The references for this report number over 300. Many of the basic documents are classified, foreign in origin or unpublished. Readers desiring information on specific topics should first refer to:

Defense Research Group, Panel on Long-Term Scientific Studies, "Report on Effects of Environmental Factors on Military Performance," NATO Report AC/243-wp/25, March-April 1969.

Additional reference information peculiar to subjects discussed in this report may be obtained by writing to the individual authors through the Department of the Army.

Editor